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DETERMINATION OF THE WELDABILITY AND ELEVATED TEMPERATURE STABILITY OF REFRACTORY METAL ALLOYS

by

G.G. LESSMANN AND D.R. STONER

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ASTRONUCLEAR LABORATORY

WESTINGHOUSE ELECTRIC CORPORATION

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FIRST QUARTERLY REPORT No. 1,

Covering the Period

June 21, 1963 to September 21, 1963

Prepared For

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NASA Contract NAS 3-2540

Technical Management
NASA - Lewis Research Center
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FOREWORD

This report describes work accomplished under Contract NAS 3-2540 during the period June 21, 1963 to September 21, 1963. This program is being administered by R. T. Begley of the Astronuclear Laboratory, Westinghouse Electric Corporation. G. G. Lessmann, project engineer, and D. R. Stoner performed the experimental investigations.

P. E. Moorhead of the Nuclear Power Technology Branch, National Aeronautics and Space Administration, is Technical Manager of this program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

This is the First Quarterly Progress Report describing work accomplished under Contract NAS 3-2540. The purpose of this program is to evaluate and catagorize promising refractory metal alloys on the basis of weldability and long time thermal stability.

Refractory metal alloys will be used extensively in advanced space electric power systems for containment of working fluids, as high temperature cladding, and for components of turbo-electric power conversion systems such as turbine blades, discs, and nozzle vanes. Their attractiveness in these applications stems primarily from their resistance to corrosion by liquid alkali metals and retention of strength at temperatures above 2000°F.

The present generation of refractory metal alloys was developed primarily for short time aero-space applications. In contrast, space power systems require reliable operation for long time periods. Thus, space power systems represent a considerable change in emphasis with regard to material properties, since long time creep strength, thermal stability, and resistance to liquid metal corrosion are the major alloy selection criteria in this application. Because the currently available refractory metal alloys were developed largely for short time applications, much additional data must be generated and evaluated before alloys are chosen for space power systems.

Initially, a general evaluation of the available alloys is being undertaken by the National Aeronautics and Space Administration to identify those materials which are most promising with respect to long time properties. The weldability and thermal stability studies discussed in this report represent one phase of this effort. The overall program is very extensive and includes concurrent corrosion and creep testing programs.

Weldability is particularly critical in the space power application because of the anticipated structural complexity of these systems, and also because welding is essential in fabrication to provide tight, trouble free joints. Thermal stability is obviously important in long time applications and is closely related to welding since it is in the weld metal and adjacent thermally distrubed base metal that damaging instabilities are most likely to occur. Hence, both the welding and thermal stability phases of this evaluation effort have been combined into one program.

II. PROGRAM SCOPE

The objective of this program is to determine the weldability and long-time elevated temperature stability of promising refractory metal alloys in order to determine those most suitable for use in advanced alkali-metal space electric-power systems.

A chronological outline of this study is shown in Figure 1, while those alloys to be included in the investigation are listed in Table I.

Each alloy will receive essentially the same evaluation. Alloys will be tested in the form of 0.035 inch sheet and 0.375 inch plate. The W-25% Re alloy will, however, be evaluated only in sheet form. The inert gas shielded arc welding and electron beam welding processes will be used. Both manual and automatic arc welding will be employed.

Weldability tests to be employed in this program were chosen on the basis of known responses of refractory metal alloys to welding and should provide a fairly broad base for alloy comparison. This effort will provide the following information:

1. A measure of alloy weld hot tear sensitivity.
2. The degree of impairment of alloy ductility resulting from welding.
3. A rough delineation of change in weldability with section size.
4. The range of weld metal properties obtainable through variation in welding parameters and processes.
5. Extent to which base metal properties can be recovered by post weld annealing.

Emphasis in the thermal stability phase of this program will be directed towards identifying primarily those structural instabilities which result in impairment of alloy ductility. Screening will be conducted first for short time (two hours)

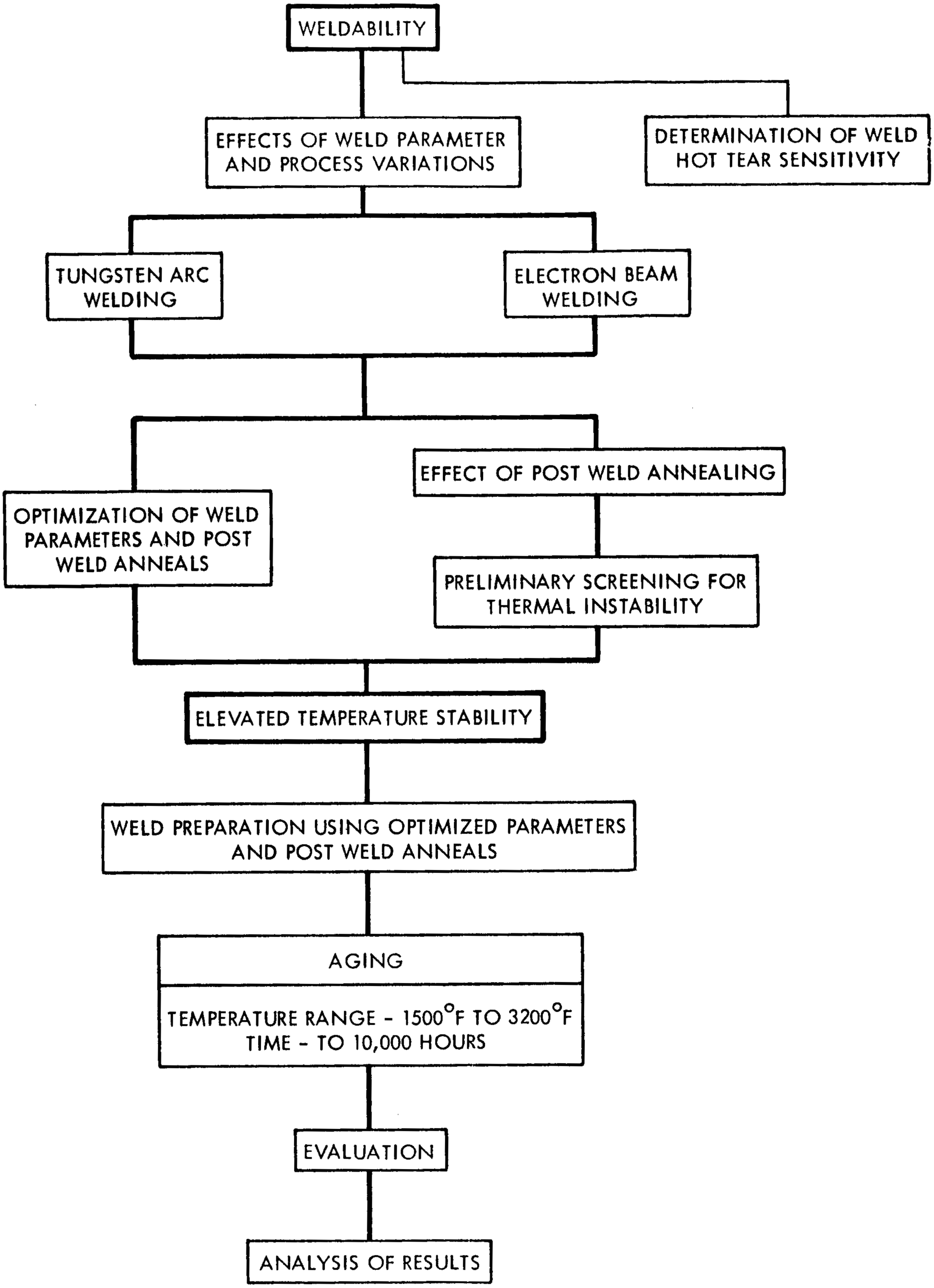


FIGURE 1 Chronological Program Outline

TABLE I. ALLOYS INITIALLY SELECTED FOR WELDABILITY AND THERMAL STABILITY EVALUATIONS

Alloy	Nominal Composition Weight Percent
AS-55	Cb-5W-1Zr-0.2Y-0.1C
B-66	Cb-5Mo-5V-1Zr
C-129Y	Cb-10W-10Hf + Y
Cb-752	Cb-10W-2.5Zr
D-43	Cb-10W-1Zr-0.1C
FS-85	Cb-27Ta-10W-1Zr
SCb-291	Cb-10W-10Ta
T-111	Ta-8W-2Hf
T-222	Ta-9.6W-2.4Hf-0.01C
Ta-10W	Ta-10W
W-25 Re	W-25 Re
W	Pure W

effects, and finally for extended periods of up to 10,000 hours duration. Temperatures as high as 3200°F will be employed. The primary objectives in this phase are:

1. Identify short time thermal effects which either degrade or improve alloy weld properties.
2. Screen alloys for impairment of properties with aging for extended periods of 100 to 10,000 hours.
3. Identify post weld anneals useful in conditioning alloys for long time high temperature exposure.
4. Identify causes as well as effects in observing alloy instabilities so that results of this investigation are useful in predicting alloy behavior in varied applications.

Process and test controls to be employed throughout this program emphasize the important influence of the interstitial elements, carbon, oxygen, and nitrogen, on the properties of refractory metals and their alloys. Even though interstitial-solute reactions provide effective strengthening in these alloys, unintentional contamination during processing and/or welding has a potent effect in degrading properties. Since the interstitial elements react readily with refractory metals at elevated temperatures, atmosphere contamination must be carefully controlled during welding and aging. Stringent test procedures are required. Arc welding will be conducted in a continuously monitored inert atmosphere. The vacuum purged weld box will be pumped to less than 10^{-5} torr before backfilling. Electron beam welding will be conducted below 10^{-6} torr and aging studies will be conducted in furnaces employing hydrocarbon free pumping systems providing a pressure less than 10^{-8} torr. Verification of the process controls will be provided by chemical sampling following successive stages of the evaluation.

The general program outline, as shown in Figure 1, will be followed. The welding study consists essentially in the determination of alloy hot tear sensitivity, optimization of weld parameters and post weld anneals with respect to weld ductility, as determined by bend testing, and screening for short time (100 hours) thermal instability of the type which occurs in columbium-1% zirconium welds.

The elevated temperature stability effort consists essentially of preparing weld specimens using optimized weld parameters and post weld anneals, aging for extended periods at high temperature, and testing. Aging tests will be conducted for periods of 100, 1000, 5000, and 10,000 hours at temperatures between 1500°F and 3200°F. Evaluation following aging will consist primarily of bend testing and room and elevated temperature tensile testing. The mechanical testing will be complemented by optical and electron metallography and chemistry.

III. SUMMARY OF WORK DONE

Seven columbium base alloys, three tantalum base alloys, W-25 Re, and pure tungsten have been selected initially for evaluation. These are listed in Table I. All alloys are being procured in the same sizes and quantities in the form of 0.035 inch thick sheet, 0.375 inch thick plate, and 0.082 inch diameter wire, except for the W-25 Re which will not be procured in the plate or wire.

Specifications were prepared for the alloys included in this program. One specification covers the tantalum base alloys and one covers the columbium base alloys. A separate specification will be written for tungsten and tungsten base alloys. Mechanical and physical property limitations were not imposed since material is being procured for evaluation only and not for specific applications. Available manufacturers specifications as well as procurement specifications were referenced on purchase orders to assure compliance with vendors advertised standards. Follow-up questionnaires were prepared and have been sent to suppliers in an effort to obtain as much specific background information as possible. Obviously, with more information available on the starting material, more comprehensive and accurate analysis of results can be made.

Order placement and delivery status for the alloys are shown in Table II. Orders have been placed on all alloys except AS-55, quoted on a best effort basis only, W and W-25 Re. At the direction of the NASA Technical Manager, a limited preliminary welding evaluation of pure tungsten is being undertaken. Tungsten sheet samples have been requested from several suppliers. Two suppliers are furnishing sheet converted from arc cast tungsten, and the others are supplying powder metallurgy sheet. This material will be welded and inspected for weld soundness, particularly freedom from porosity. Based upon these results, material will be ordered for complete evaluation.

TABLE II ALLOY PROCUREMENT AND DELIVERY SCHEDULE

Alloy	NTPB Approval	Req-For Quote	Quote Rec'd	Order Placed	Promised Shipping Date	Actual Delivery			Supplier
						Sheet	Plate	Wire	
AS-55	8/12	9/9	10/1						General Electric
B-66	8/12	7/26	8/19	8/29	10/18			11/8	Westinghouse
C-129Y	8/12	9/9	9/20	10/2	11/30				Wah Chang
Cb-752	8/12	9/9	9/19	10/21	11/30				Haynes
D-43	8/12	7/26	8/17	9/3	11/8	11/15	10/18		DuPont
FS-85	8/12	7/26	8/12	8/22					Fansteel
SCb-291	8/12	9/9	9/17	10/2	11/30				Stauffer
T-111	8/12	7/26	8/16	9/27	10/28				NRC
T-222	---	9/9	9/25	10/21	1/15/64				Westinghouse
Ta-10W	8/12	7/26	8/12	8/22	9/30	10/21	10/3	10/17	Fansteel
W-25 Re	8/12	11/8							
W	---								

A compilation of available background material on the various alloys was initiated. This effort will naturally continue throughout the program. As indicated above, very limited long time data are available. A comparison of short time properties for columbium has been reported elsewhere[15], and a brief summary of tensile properties for all alloys are included in this report.

A summary of bend ductility test results is also included in this report. This compilation is of particular interest since bend testing will be used extensively in this program to evaluate the effects of both welding and aging. The bend test is technically a fairly complex test for which no one procedure has yet gained sufficient industry wide acceptance to be considered a standard test. Consequently, comparable quantitative results are obtained only by testing alloys at one facility. However, a fairly qualitative comparison between alloys based on available data appears reasonable and is included in this report.

The tungsten arc and electron beam welding equipment were checked out. Satisfactory welds were produced in sheet samples of the T-111, T-222, B-66, and B-33 (Cb-5V) alloys by both welding processes.

Design of tooling including special water cooled welding torches, improved clampdown fixtures, traversing tables, and bend test equipment was completed and tooling fabrication was initiated. Weld box atmosphere monitoring equipment has been procured and a calibration and sampling manifold was designed and fabricated.

IV. TECHNICAL PROGRAM

A. ALLOY PROCUREMENT AND EVALUATION: Only limited quantities of the material required for this program have been received. The alloys included in this evaluation are essentially special order, non-stocked items, which, with a few exceptions, are not yet used extensively in hardware applications. As a result, procurement lead-time for these alloys is fairly long as shown in Table II. An additional consequence of this situation is that data normally required for preparation of tight specifications does not exist. The procurement specifications, included in Appendix A, reflect this limitation as would reasonably be expected. Specifications were prepared which were therefore directed primarily towards assuring compliance with good standards of quality, and, for the majority of alloys which are considered more or less commercial, towards obtaining material representative of current practice.

In addition, a questionnaire and cover letter has been sent each supplier which briefly describes our requirements in this program, and which also solicits available information on material furnished for this program. This questionnaire and cover letter are included in Appendix B.

Minimum heat sizes for the various alloys are called out in the purchase specifications while a minimum sheet size of 12 inches x 24 inches and plate size of 6 inches x 12 inches are called out on the respective purchase orders. Chemistry limits included in the specifications where furnished by the manufacturers. These do not appear to be particularly reasonable for the columbium alloys with respect to interstitial element contents, which probably must be kept considerably lower than the maximum levels specified. In an effort to define the chemistry limitations more clearly, the specifications require that the analyses of the five ingots prior to the one from which material for this program was furnished be reported. Where vendors furnished manufacturing specifications, these were also called out on respective purchase orders. As this evaluation proceeds, the specifications will be improved to reflect the experience gained with these alloy systems.

The seven columbium base alloys and three tantalum base alloys presently included in this program are listed, with nominal compositions, in Table I. Pure tungsten is also included in this program. Of these alloys, SCb-291 and Ta-10W are solid solution strengthened alloys. Alloys containing either of the reactive elements zirconium or hafnium, without intentional interstitial additions, also rely primarily on solid solution strengthening even though some dispersion strengthening may be realized. This group included B-66, C-129Y, Cb-752, FS-85, and T-111. The remaining alloys AS-55, D-43, and T-222 definitely rely upon dispersion strengthening as well as solid solution strengthening.

The selection of alloys for this program was based on creep tests conducted at the Lewis Research Center, the results of which are as yet unpublished. To provide a very general comparison between alloys, reported 2000°F and 2400°F tensile data are summarized in Appendix D. The data shown are for recrystallized specimens and do not therefore necessarily represent the condition for optimum strength nor can these data be used as a measure of comparative creep strength. Obviously, many factors, including test variability, affect tensile values obtained. Hence, the order in which these alloys are listed can change considerably and this data is therefore presented only for general interest.

The tantalum base alloys obviously suffer a disadvantage because of their high density. However, their fabricability is generally superior to that of columbium alloys. A recent and more complete comparison of properties of columbium alloys has been made by White and Cortez.[15]

Bend test results for the alloys are summarized in Figure 2. A considerable spread in values for most alloys is apparent. This results from the multitudinous test procedures employed, the variation in base metal conditions, variation in interpretation of results, and also, in the case of weld metal tests, variation in welding parameters and processes. This information, however vague and incomparable, is of particular interest in this program since bend testing will be used extensively as an evaluation technique. Hence, reported bend test data has been recorded in detail. This information is included in Appendix C on bend test data record forms for each alloy. Test conditions and references are indicated as well as test results. In view of the early stage of the present program, a detailed discussion and comparison of the bend ductility of the various alloys will be deferred until additional data have been generated. Mechanical test procedure requirements for bend testing as established by the Materials Advisory Board will be adhered to in the conduct of this program.

B. <u>WELDING STUDIES</u>: For the most part the 0.035 inch sheet will be butt welded automatically using the tungsten arc and electron beam welding processes. Sheet will be welded without the addition of filler metal. The 0.375 inch plate will be welded manually using the tungsten arc welding process with the addition of filler metal.

The principal means of weld evaluation in this program will be by bend testing over a temperature range to identify effects of welding and aging on the bend ductile-to-brittle transition temperature. This effort will naturally be complemented by metallography, hardness measurements, tensile testing, chemical analyses and electron fractography to assist in identifying the underlying metallurgical reactions.

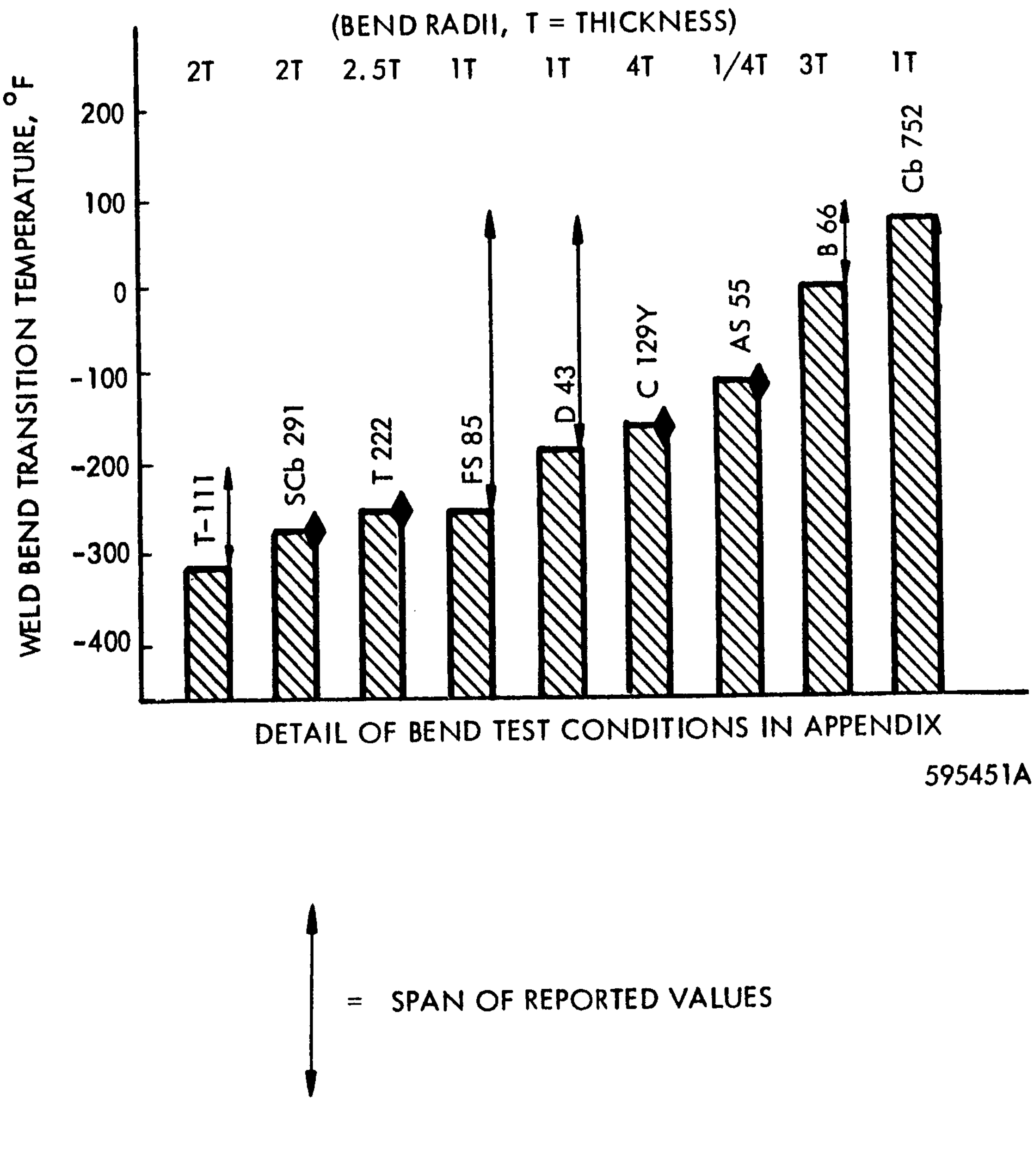


FIGURE 2 Weld Bend Transition Temperature Summary

High restraint patch tests in both sheet and plate material will be used for determining alloy weldability as measured by weld hot tear sensitivity. These tests are fairly common, and particularly in thin gages are generally more discriminating than butt welds[13,24]. Specimen designs for these tests are shown in Figures 3 and 4. A typical bead-on-plate patch test is shown in Figure 5. As can be seen, the sheet is heavily distorted, demonstrating the the severity of weld shrinkage stresses realized in this test. Both the sheet and plate patch tests are made manually.

Welding data on refractory metal alloys has shown that weld parameters have a pronounced effect on as-welded bend ductility[27], and that bend ductility is an excellent criterion for assessing alloy thermal stability. As a starting point for this program, welding parameters will be evaluated over a practical range of values and optimized with respect to as-welded ductility. Hence, all consequent aging studies can be conducted on welds produced initially with the best as-welded ductility. Welding parameters will be varied individually where possible, and extreme care will be exercised in maintaining consistent welding conditions. This is very important since co-incidental effects could cancel one another as determined in post-weld testing. As an example, if an alloy proved sensitive to unit weld length heat input rather than merely welding speed, effects could easily be cancelled by lowering the cooling rate (i.e. vary the hold down and clamping arrangement) simultaneous with increased welding speed. Obviously the inter-relationship between weld parameters and metallurgical effects is extremely complex, and it will be essential to emphasize the most important. Published information does exist on the effects of variation of parameters for several of the refractory metal alloy systems and results of these investigations will be incorporated into this effort.

Choosing reasonable ranges for variation of welding parameters in

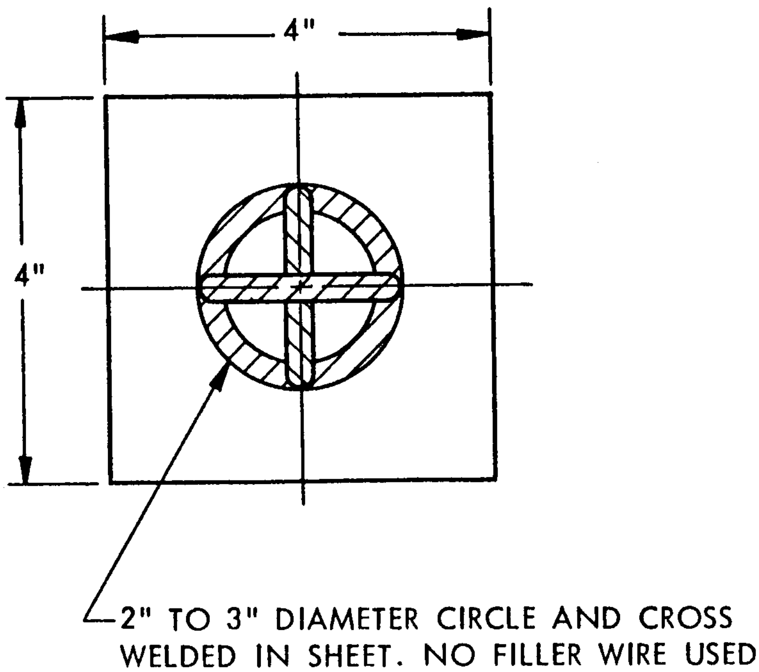


FIGURE 3 Bead-on-Plate Restraint Patch Test Design for Sheet Material

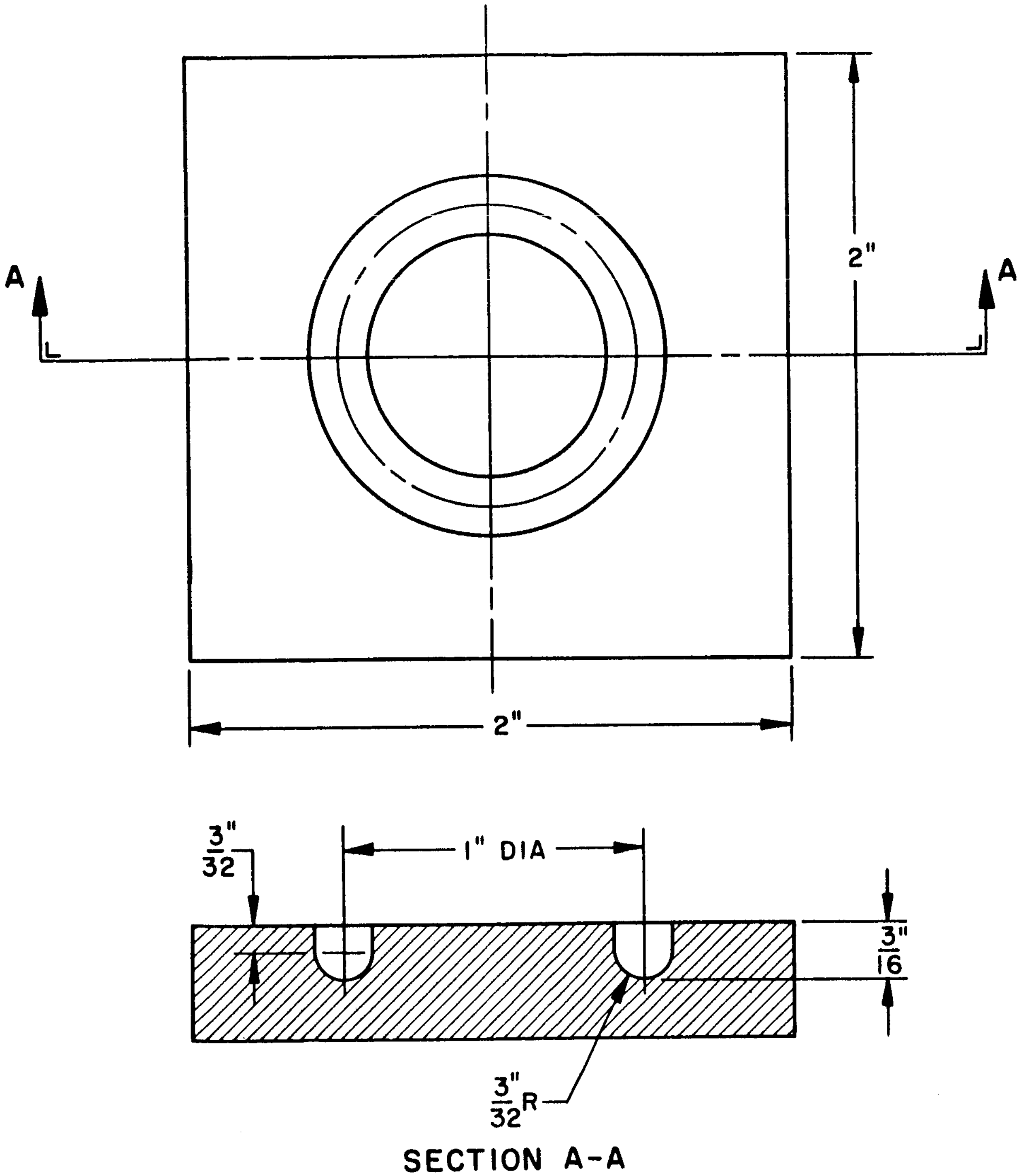
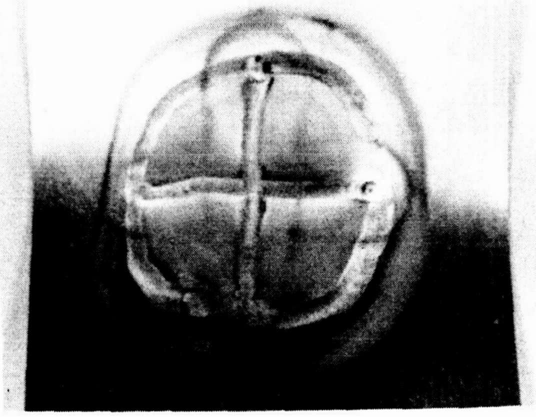


FIGURE 4 Circular Groove Weld Restraint Test Specimen for Plate Material



DX 601

FIGURE 5 Typical Bead-on-Plate Patch Test in Heat DX-601 of B-66 Alloy. 0.6X tungsten arc welding should present no particular problems since there is presently considerable published information available. On the other hand, welding parameters for high voltage electron beam welding of the refractory metal alloys are not particularly well established and more discrimination will be required in this phase.

Preliminary electron beam welding of available sample material of B-66, T-222, and B-33 (Cb-5V) was undertaken employing the 2KVA welder described later in this report. This effort was aimed at establishing weld parameter ranges. Four different thicknesses of B-66, one of B-33, and one of T-222 were evaluated for weld penetration. The electron beam welding parameters considered were accelerating voltage (KV), beam current (milliamps), and welding speed. To eliminate variability in the electron beam spot size, the beam was focused to the smallest spot diameter (approximately 0.010 inch) after each change of either beam accelerating voltage or current. In some instances, however, a defocused and wider spot would be desirable. Beam deflection either parallel or perpendicular to the weld can be introduced as an additional variable in this process. Typical weld beads of B-66 and T-222 are shown in Figures 6 and 7.

Enough weld passes (56 total) were made on B-66 sheet to develop a plot of power requirements for penetration depths. These tests are summarized in Figure 8 along with values for one thickness of B-33 and T-222. Power input is expressed in joules (watt seconds) per inch, and, as a comparison, a TIG butt weld of 0.030 inch thick B-66 sheet would require about 7000 joules per inch compared to 400 for electron beam welding. B-33 required more power than B-66 for equivalent penetration possibly because of its greater thermal conductivity. T-222 penetration requirements were similar to B-33.

Preliminary weld ductility bend tests of 0.9 T radius were run on three

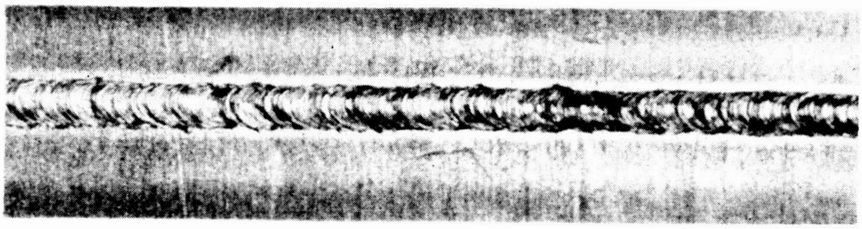


FIGURE 6 Electron Beam Weld in T-222, Top View. 7X

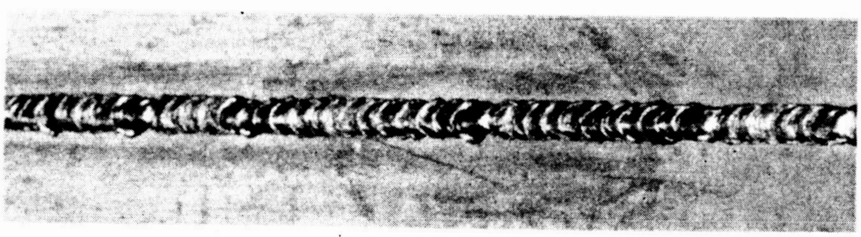


FIGURE 7 Electron Beam Weld in B-66, Top View. 7X

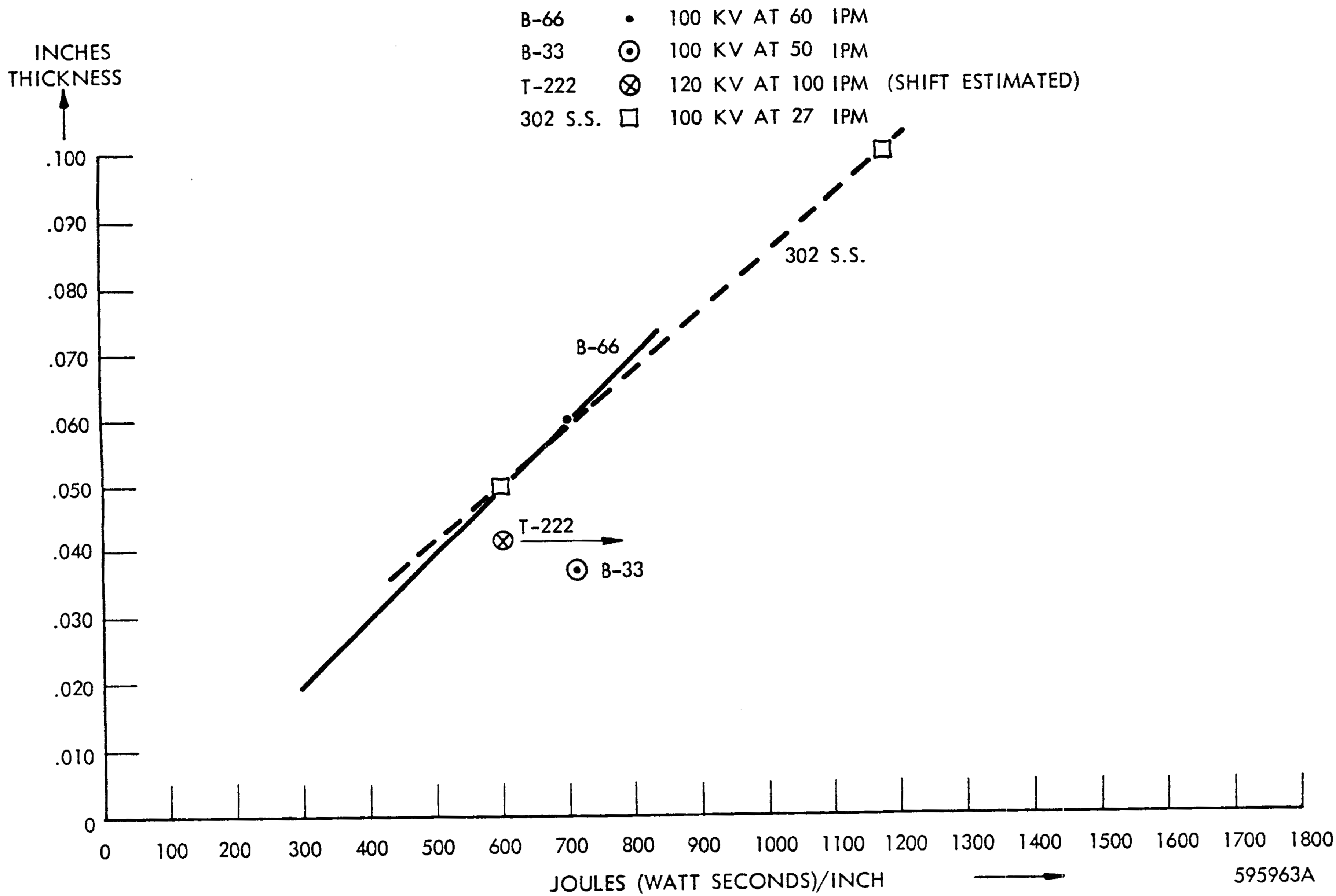


FIGURE 8 Electron Beam Weld Penetration vs. Power Input

samples of electron beam welded B-66 producing 90° ductile bends at -200°F. Transverse and longitudinal specimens of 0.043 inch sheet were bent at 10 ipm over a 15 T span. Welding parameters were 110 KV, 6 MA, and 70 ipm with a focused beam deflected 0.048 inch in the weld direction.

C. WELD ATMOSPHERE CONTROL: Because of the marked sensitivity of refractory metal alloys to interstitial contamination, continuous measurement and control of welding atmospheres are required to assure that test results are consistant and meaningful. This problem is minimized in electron beam welding during which vacuum monitoring provides a measure of atmosphere purity. Arc welding in an inert atmosphere however represents a considerably more complex monitoring problem. This discussion will therefore deal with the measures being taken to monitor the inert gas atmosphere during arc welding.

All TIG welding will be done in a vacuum purged weld chamber pumped to below 10^{-5} torr before backfilling. Using this procedure rather than welding in air with trailing shields and gas backup, the welding atmosphere is easily defined and consequently more easily monitored. Current welding practice usually provides an initial high purity welding atmosphere by gas supply analysis and chamber evacuation or purging, but a possible degeneration of atmosphere quality during welding is seldom considered.

The objective in this program is to provide an initial welding atmosphere containing less than 10 ppm oxygen which will be monitored during welding and held to a level of less than 30 ppm O_2 at all times. Oxygen and moisture content of the inert welding atmosphere will be monitored. These were chosen primarily because meters for this function are commercially available. It is felt, however, that measurement of oxygen and moisture will in fact provide a measure of total gas impurity levels. This hypothesis will be checked by selected total impurity measurements using mass spectrometer analyses.

Liquid electrolyte oxygen and moisture meters will be connected permanently to the system while a solid electrolyte oxygen cell may also be added. These meters are described more completely in the equipment section of this report.

A gas sampling analysis and monitoring system has been designed which incorporates several important features. A schematic of this system is shown in Figure 9. The manifold design, as can be seen, permits rapid changeover from standardized calibration gases, to the weld box, or to gas supply bottles without "breaking" the system to air. Hence, the meters are on the line continuously. A nitrogen bottle is also connected to the manifold for purging the gages during down time, keeping them clean during stand-by periods. Only during changeover of supply bottles is this system broken, and, because of the valving arrangement, this effect is localized.

All bottled gas connected to this system will be checked prior to use in the welding chamber. This has been found necessary since individual bottles are not furnished with a check analysis except at considerable expense, and because the high purity bulk gas supply is easily contaminated during transfer to standard delivery bottles. Once a bottle has been checked, it can be valved directly into the welding chamber without breaking any connections.

Total impurity determinations will be made periodically so that the complete welding atmosphere is known. This will be done to compliment the continuous monitoring apparatus. A $\frac{1}{2}$ liter sample bottle attached to the weld chamber will be used for this purpose. Samples will be taken at various times during early welding runs as a means of measuring degradation of the atmosphere during welding. Helium samples obtained in this manner will be concentrated by cryogenic pumping for mass spectrographic analysis. This technique provides a highly accurate method of helium analysis[28].

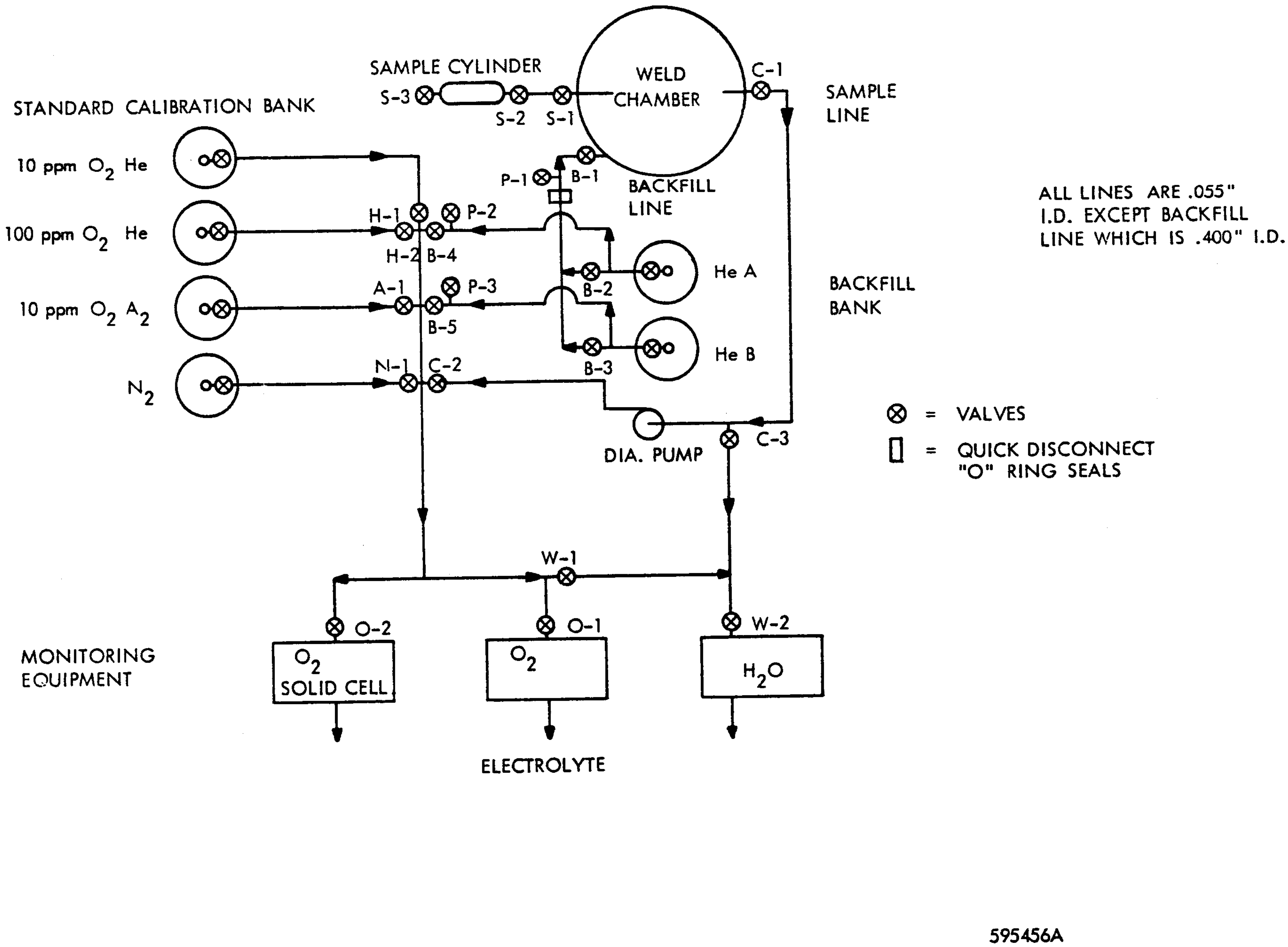


FIGURE 9 Schematic of Gas Sampling and Monitoring System

D. ANNEALING AND AGING: The effects of post weld annealing and long time aging will be evaluated in this program using high vacuum furnaces. Furnaces have been designed to provide a pressure during aging of less than 10^{-8} torr and total contamination pickup is anticipated to be less than 100 ppm. Aging and annealing temperatures will be between 1500°F and 3200°F. Present plans call for aging runs of up to 10,000 hours duration.

The furnace design is essentially complete. The vacuum chamber will be bakeable to 250°C. Only metal-to-metal seals will be employed. The pumping system will be hydrocarbon free using cryogenic-molecular seive pumping for roughing and sputter ion pumps for high vacuum pumping and system holding. Furnace heating will be accomplished using resistance heated tantalum or tungsten mesh elements having a split tube configuration common in high vacuum furnaces. A more detailed description of the aging furnaces will be given in later reports in this program.

E. EQUIPMENT

1. Arc Welding: Tungsten arc welding will be accomplished using a three phase, direct current Vickers 300 ampere welder equipped with a precision weld programmer. It is anticipated that welding will be done using only straight polarity. This welder can be used in a fully automatic mode with synchronous motor timers providing accurate sequence programming including hot starts, up or down starting slopes, and tail slopes. The unit is also equipped with foot controls for manual welding.

The Vickers welder, recorders, and vacuum purged weld chambers are shown in Figure 10. The weld chamber is of a special design having flat sides with an octagonal shaped cross section. The inside dimension across flats is 42 inches. Overall inside length is 48 inches, but the design permits the addition of either 20 inch diameter or full chamber size extensions. The pumping system consists of

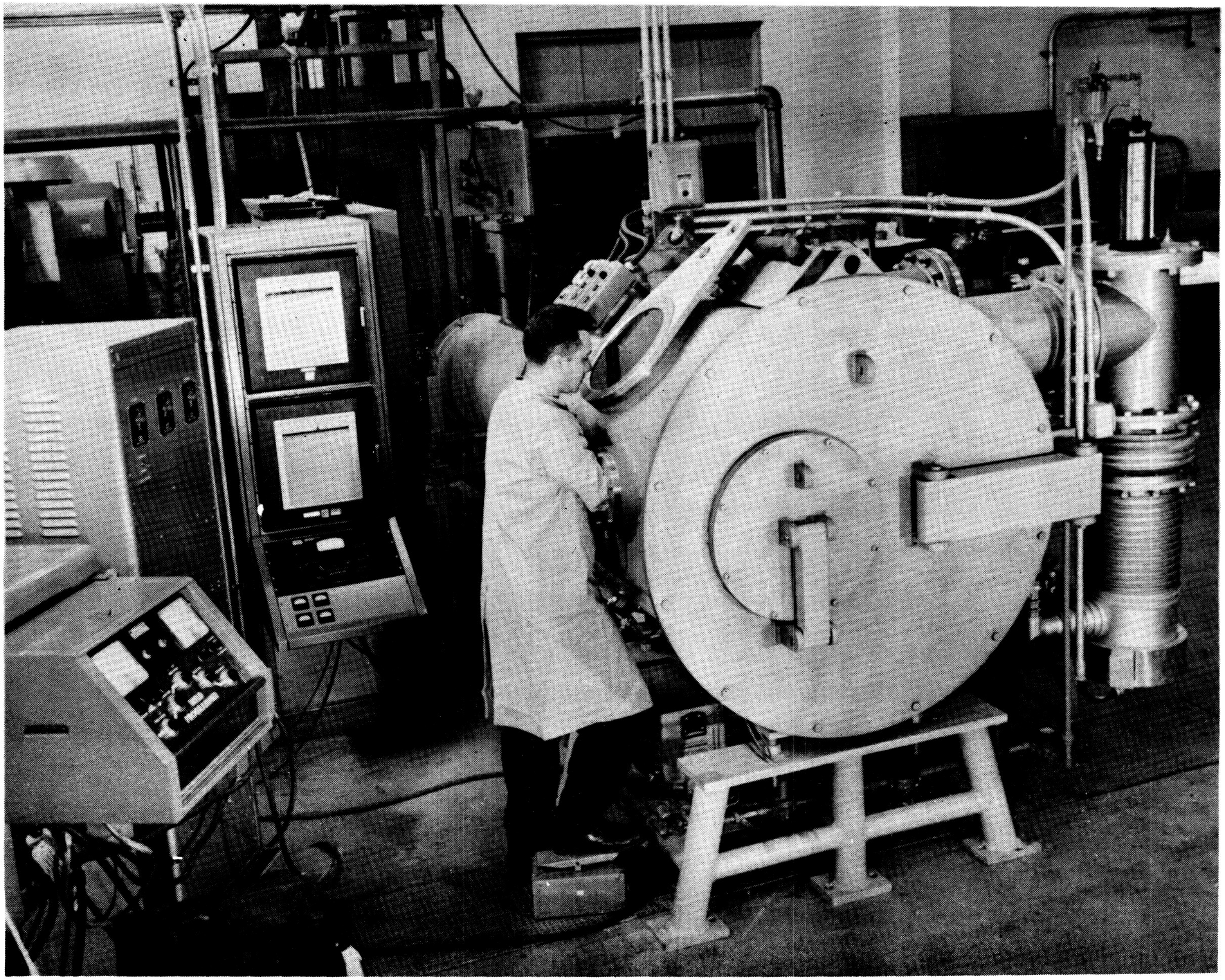


FIGURE 10 Vacuum Purged Weld Chamber with Welder and Controls

an NRC 10 inch diffusion pump backed in series by a Heraeus roots blower and compound Kinney pump for roughing and holding.

2. Weld Atmosphere Monitors: Gas analysis equipment which will be used to monitor the vacuum purged weld box atmosphere includes the following:

(a) A Lockwood and McLorie Model L Trace Oxygen Analyzer. This analyzer is based on a simple coulometric process. Oxygen in the sample stream is quantitatively reduced by electrolysis in a KOH solution according to the equation $O_2 + 2\ H_2 + 4e \rightarrow 4OH^-$. The electrolysis current measured indicates the original sample content. All the oxygen in the gas stream is reduced. Hence, the instrument is flow rate sensitive, and, additional ranges of operation are possible through variation of flow rate.

Basically the instrument has a range of 0-2000 ppm O_2 with a low scale range of 0-20 ppm O_2. Accuracy is reported to be $\pm$ 5% or 0.1 ppm. The sensitivity is 26.3 microamps per ppm O_2 by volume. The instrument is equipped with sensitivity checking cell as well as an analyzing cell.

(b) A Consolidated Electrodynamics Corporation Portable Moisture Monitor. In this unit sample gas is drawn through a strong dessicant, and moisture present is related to an electrolysis current. The cell is a glass tube with two platinum wires, wound in a helix, composing the electrolysis electrodes. The space between the wires is coated with phosphorous pentoxide (P_2O_5), a strong dessicant, which becomes electrically conductive when wet. A potential applied to the wires produces a measurable and calibrated electrolysis current when moisture wets the P_2O_5. Electrolysis of the water continuously regenerates the cell permitting it to continuously measure all the moisture in the sample stream.

The range of this instrument is 0-1000 ppm with a low range scale of 0-10 ppm. A 63% response to a stepwise change in either direction between 50 and

1000 ppm will occur in 30 seconds or less.

(c) A Westinghouse Oxygen Gauge. This instrument may be employed to compliment the other instruments. This unit uses a solid electrolyte operating at 1560°F. The sample gas is passed through a ceramic electrolyte tube plated with platinum on the inside and outside surfaces. The outside surface of the tube is exposed to the atmosphere, providing a constant oxygen partial pressure of 0.2 atmosphere. The emf generated between the inner and outer surfaces of the tube is proportional to the logarithm of the ratio of oxygen partial pressures according to the Nernst equation:

$$\text{EMF (Volts)} = \frac{RT}{nF} \ln \frac{P_{O_2}(II)}{P_{O_2}(I)}$$

where R is the gas constant, T is the temperature in °K, F is the Faraday constant, n is the number of electrons transferred in the electrode reaction $O_2 + 4e \rightleftarrows 2O^{=}$, $P_{O_2}(II)$ is the partial pressure of oxygen in air, and $P_{O_2}(I)$ is the partial pressure of oxygen at the inner electrode. A change in oxygen concentration of 1 to 10 ppm produces the same change in voltage as a change from 100 to 1000 ppm. The advantage of this instrument is a large range, 1 to 200,000 ppm O_2, and rapid response time, 10^{-3} seconds[16]. However, a combustible vapor background in the sample gas generally combines with the available oxygen throwing the meter off scale.

(d) The manifold system, combining supply bottle, calibrated bottle, and weld box testing as well as weld box backfilling, employs only stainless steel tubing and brass valves. Welded, brazed, or metal-to-metal seals are employed as much as possible to assure cleanliness. Small diameter tubing (0.055 inch I.D.) to provide a rapid overall system response time, less than 3 seconds from weld box to meter, and small system surface area is used in the sampling system. Response time using ¼ inch tubing would be increased to 30 seconds.

Special gaugeless regulators employing stainless steel diaphragms and metal-to-metal seals are used on the oxygen doped standard tanks to assure accurate instrument calibration.

3. Bend Test Fixtures: An open view of the sheet bend test fixture is shown in Figure 11. This fixture is made entirely of A2 tool steel (5Cr-1Mo-1C) hardened to R_c55. This unit is equipped with both a liquid nitrogen cryostat for testing to -320°F, Figure 12, and a heater for testing up to 700°F. Interchangeable punches of varying radii are provided.

Larger punches have center holes to permit insertion of control thermocouples which measure the test temperature at the exact tangent point between punch and bend specimen. The specimen supports are adjustable to vary the test span.

This unit is used in conjunction with a 500 lb. Instron, a 10,000 lb. Instron, or a 60,000 lb. Wiedemann Baldwin universal tensile testing machine having travel speeds of up to 20 ipm.

4. Electron Beam Welding

(a) Hamilton-Zeiss Electron Beam Welder, Model W1-2. This is a variable voltage unit capable of 150,000 volts, with a maximum beam current of 20 ma. The beam has fine focus control (0.010 inch diameter of full power), and can be pulsed to 3000 cps, or oscillated to 60 cps. The gun is of the Steigerwald type. Options incorporated into this gun include a circle generator, long working distance ($\frac{1}{2}$ inch to 15 inches), and beam current rise and fall (slope) control. This is an integral unit and includes a modified vacuum chamber for welding below 10^{-6} torr, and drive table fixturing for traversing weld components.

(b) Hamilton-Zeiss Electron Beam Welder, Model WO-2. This is also a variable voltage unit capable of operating at a maximum of 150,000 volts.

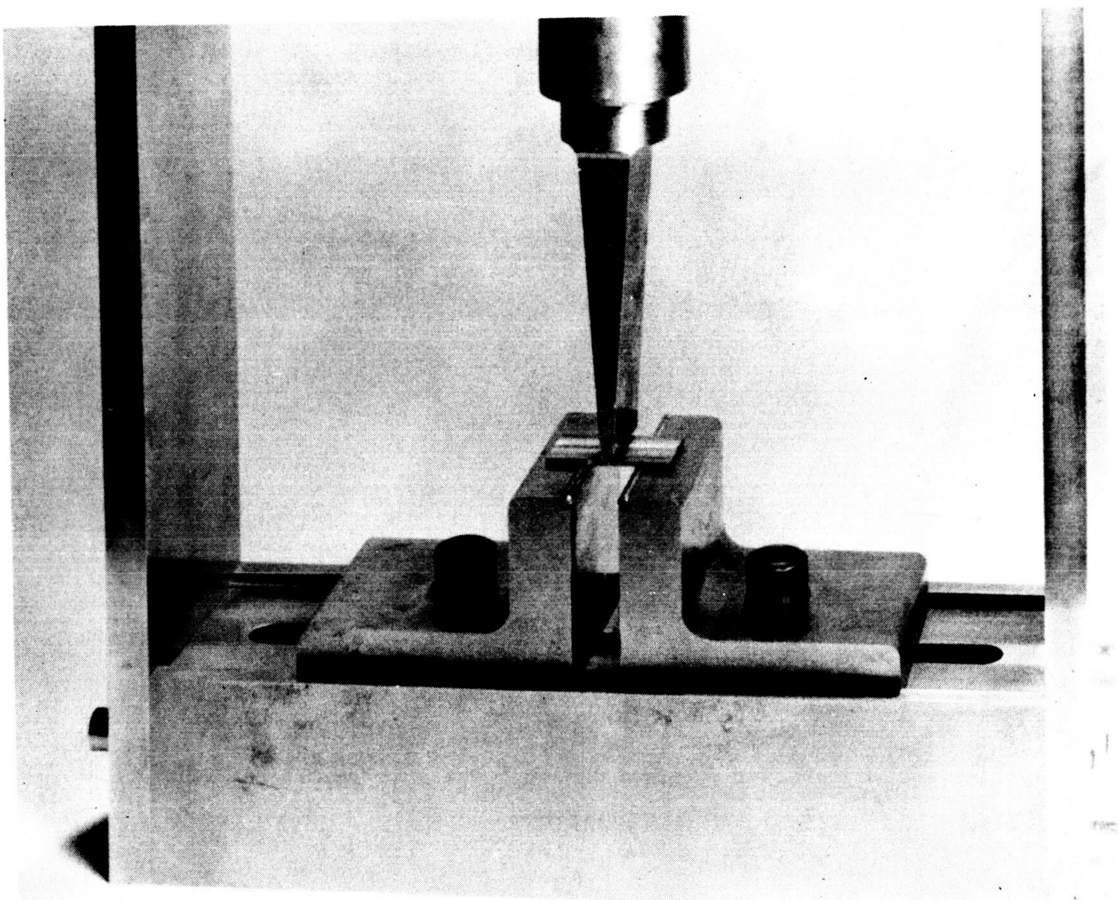


FIGURE 11 Open View of Bend Test Fixture

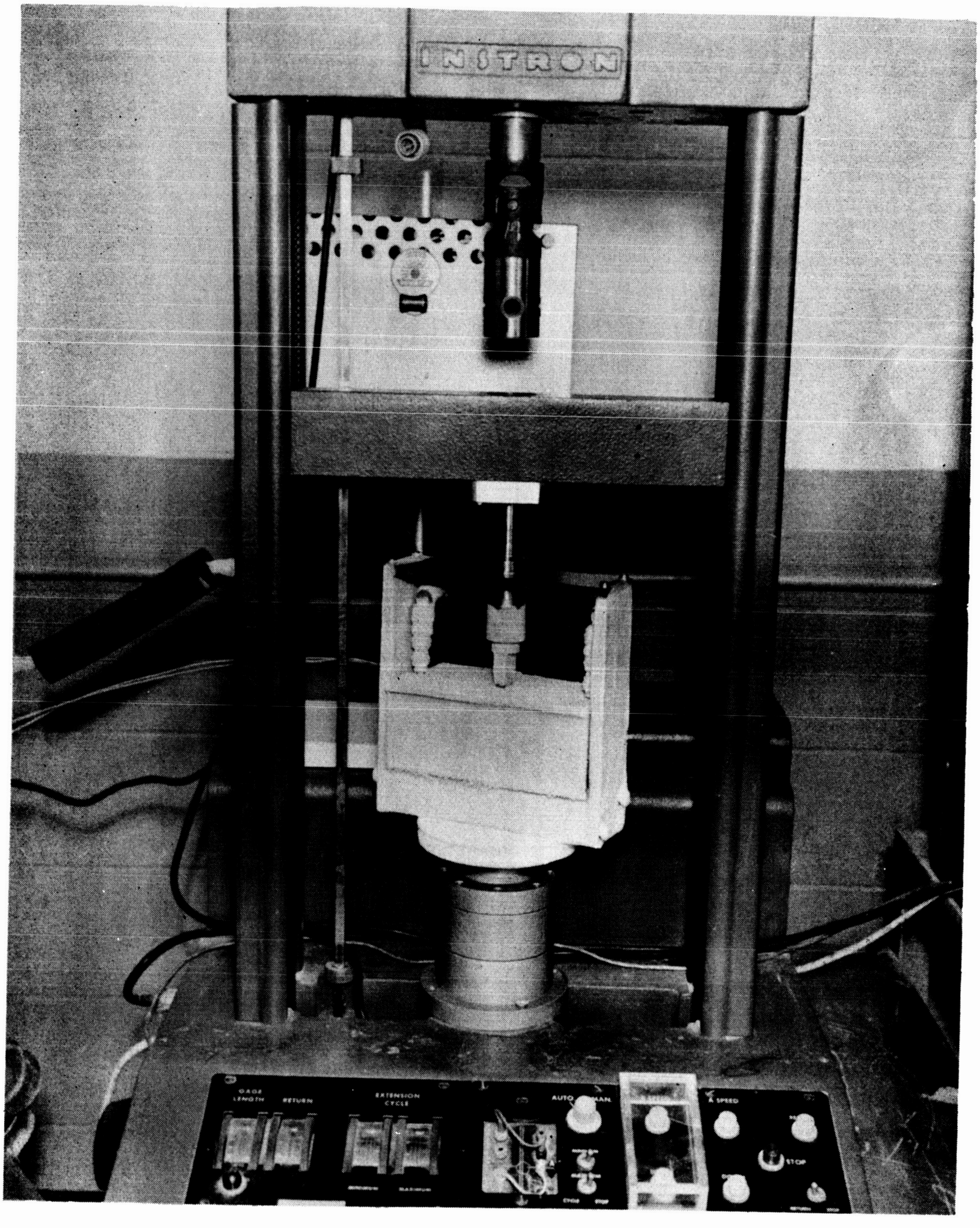


FIGURE 12 Bend Test Fixture with Liquid Nitrogen Cryostat

Maximum beam current is 13.5 ma and minimum spot size of 0.010 inch diameter, with a power density of 25,000 KW per square inch. This gun does not incorporate a circle generator. The gun is mounted integrally with a vacuum welding chamber.

IV. FUTURE WORK

During the next quarterly period most of the material for this program will be received and inspected, and final action will be taken on the alloys which have proven difficult to obtain in the limited quantities required in this program. Initial tungsten weld tests will be completed, a specification will be prepared, and an order will be placed.

Following checkout of the special welding torches and fixtures, electron beam and tungsten arc welding studies will be initiated.

Monitoring of the vacuum purged weld chamber inert atmosphere will be reduced to practice and applicable standard operation procedures will be prepared.

Review of the aging furnace designs will be completed and furnace construction will be initiated.

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VII. APPENDIX A

Alloy Specifications

Westinghouse Electric Corporation
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pa. 15236
(Fed. Ident. Code No. 14683)

PURCHASING DEPARTMENT SPECIFICATION WANL Ta 2-A
(Not for Publication)

TENTATIVE SPECIFICATION
September 3, 1963

TANTALUM ALLOY SHEET AND PLATE

1. GENERAL

1.1 This specification covers commercial tantalum alloy sheet and plate, intended for structural fabrication by the tungsten arc and electron beam welding processes, and designated as follows:

P D Spec Designation	Description
Ta 2 -1	T-111 alloy sheet and plate
Ta 2 -2	Ta-10W alloy sheet and plate
Ta 2 -3	T-222 alloy sheet and plate
Ta 2 -4	

NOTE: Unless otherwise specified, the following requirements apply to all designations.

1.2 No change shall be made in the quality of successive shipments of material furnished under this specification without first obtaining the approval of the purchaser.

2. MANUFACTURE

2.1 PROCESS: Material furnished to this specification shall be from a commercial heat of 400 pounds minimum ingot size produced by the electron beam and/or consumable electrode arc melting processes.

2.2 CONDITION: The manufacturer shall furnish the sheet or plate in the recrystallized condition and shall certify as to that condition per the requirements of Section 7.

3. CHEMICAL PROPERTIES AND TESTS

3.1 CHEMICAL COMPOSITION: The material shall conform to the following composition:

	Per Cent			
Element	Ta 2 -1	Ta 2 -2	Ta 2 -3	Ta 2 -4
Carbon	.004 max.	.005 max.	0.008 - 0.015	
Oxygen	.003 max.	.007 max.	0.003 max.	
Nitrogen	.003 max.	.003 max.	0.003 max.	
Hydrogen	.0006 max.	.0006 max.	0.0006 max.	
Columbium	.100 max.	.100 max.	0.100 max.	
Iron	.010 max.	.007 max.	0.007 max.	
Molybdenum	.030 max.	.030 max.	0.030 max.	
Nickel	.007 max.	.007 max.	0.007 max.	
Tungsten	7.0 - 9.0	8.5 - 11.0	9.0 - 10.0	
Hafnium	2.0 - 2.8	----	2.1 - 2.8	
Tantalum	Remainder	Remainder	Remainder	

3.2 CHECK ANALYSIS: An analysis of each ingot shall be made by the manufacturer to determine the percentages of the elements specified in Section 3.1. The chemical composition thus determined shall conform to the requirements specified in Section 3.1. The manufacturer shall demonstrate that the heat furnished is in fact typical by reporting the composition of the five ingots of this alloy produced just prior to the ingot used to fill this order. Percentages of the elements specified in Section 3.1 shall be reported for each heat.

4. MECHANICAL PROPERTIES AND TESTS

4.1 BEND TEST: Sheet in thicknesses up to 0.060 inch shall be capable of being bent a full 180° back upon itself, at room temperature, without cracking in the face of the bend.

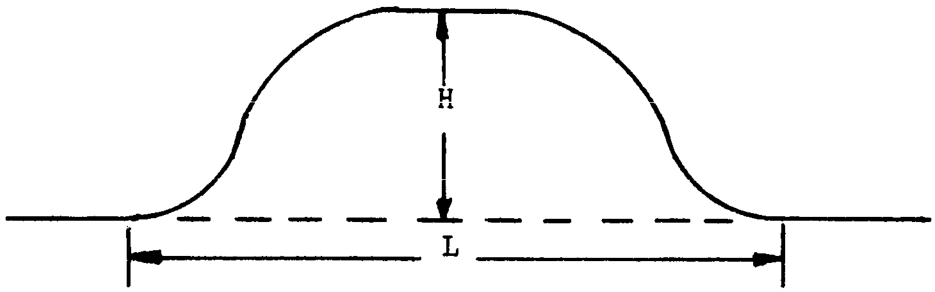
5. DIMENSIONS AND FINISH

5.1 WORKMANSHIP: Material shall be uniform in quality and condition, clean, sound, smooth, and free from "oil cans" of depth in excess of the flatness tolerances, ripples, foreign materials, and internal and external imperfections detrimental to fabrication or performance of the material.

5.2 SIZE: Where required, minimum sizes will be specified on the purchase order.

5.3 FLATNESS: Flatness tolerance shall not exceed five per cent as determined by the following formula:

$$\% \text{ Flatness} = \frac{H}{L} \times 100$$



Where: H is equal to the maximum distance between a flat reference surface and the lower surface of the sheet or plate, and L is equal to the minimum distance between points of contact of the sheet or plate with the flat reference surface.

If a general bow in the material can be eliminated by slight pressure without ends coiling or an "oil can" effect resulting, the material will be accepted.

6. OTHER REQUIREMENTS

When indicated on purchase orders, requirements not listed above or requirements more severe than those listed above which are referenced by a supplier's manufacturing specification will be adhered to.

7. TEST REPORTS

The manufacturer shall furnish five copies of a certified test report showing the results of the tests specified in Sections 3, 4, and 5 and bearing a statement as to the condition of the material as specified in Section 2.2. The report shall show the Purchase Order Number; P D Specification Number including dash number and sub letter; Per Cent of the Final Reduction; Temperatures of the Anneals Before and After the Final Reduction; Dimensions; Heat Number; and Name of Manufacturer.

8. PACKING AND MARKING

8.1 PACKING: The sheet or plate shall be packed in such a manner as to prevent injury during shipment.

8.2 MARKING: Each sheet or plate shall be marked showing the P D Specification and Dash Number; Heat Number; Manufacturer's Identification; Nominal Thickness in Inches. The marking shall be sufficiently stable to withstand ordinary handling.

Westinghouse Electric Corporation
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pa. 15236
(Fed. Ident. Code No. 14683)

PURCHASING DEPARTMENT SPECIFICATION WANL Cb 1-A
(Not for Publication)

TENTATIVE SPECIFICATION
September 3, 1963

COLUMBIUM SHEET AND PLATE

1. GENERAL

1.1 This specification covers commercial columbium alloy sheet and plate, intended for structural fabrication by the tungsten arc and electron beam welding processes, and designated as follows:

P D Spec Designation	Description
Cb 1 -1	B-66 columbium sheet and plate
Cb 1 -2	D-43 columbium sheet and plate
Cb 1 -3	FS85 columbium sheet and plate
Cb 1 -4	Cb 752 columbium sheet and plate
Cb 1 -5	SCB291 columbium sheet and plate
Cb 1 -6	C129Y columbium sheet and plate
Cb 1 -7	AS55 columbium sheet and plate

NOTE: Unless otherwise specified, the following requirements apply to all designations.

1.2 No change shall be made in the quality of successive shipments of material furnished under this specification without first obtaining the approval of the purchaser.

2. MANUFACTURE

2.1 PROCESS: Material furnished to this specification shall be from a commercial heat of 200 pounds minimum ingot size produced by the electron beam and/or consumable electrode arc melting processes.

2.2 CONDITION: The manufacturer shall furnish the sheet or plate in the recrystallized condition and shall certify as to that condition per the requirements of Section 7.

3. CHEMICAL PROPERTIES AND TESTS

3.1 CHEMICAL COMPOSITION: The materials shall conform to the composition specified in Table I.

3.2 CHECK ANALYSIS: An analysis of each ingot shall be made by the manufacturer to determine the percentages of the elements specified in Table I. The chemical composition thus determined shall be reported to the purchaser and shall conform to the requirements specified in Table I. The manufacturer shall demonstrate that the heat furnished is in fact typical by reporting the composition of the five ingots of this alloy produced just prior to the ingot used to fill this order. Percentages of the elements specified in Table I shall be reported for each heat.

4. MECHANICAL PROPERTIES AND TESTS

4.1 BEND TEST: Sheet in the thicknesses up to 0.060 inch shall be capable of being bent a full 180° back upon itself, at room temperature, without cracking in the face of the bend.

4.2 OTHER DUCTILITY: Other ductility requirements shall be as specified on the purchase order.

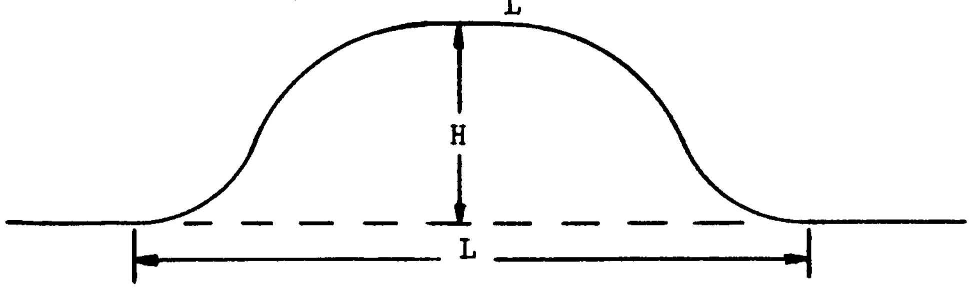
5. DIMENSIONS AND FINISH

5.1 WORKMANSHIP: Material shall be uniform in quality and condition, clean, sound, smooth, and free from "oil cans" of depth in excess of the flatness tolerances, ripples, foreign materials, and internal and external imperfections detrimental to fabrication or performance of the material.

5.2 SIZE: Where required, minimum sizes will be specified on the purchase order.

5.3 FLATNESS: Flatness tolerance shall not exceed five per cent as determined by the following formula:

$$\% \text{ Flatness} = \frac{H}{L} \times 100$$



Where: H is equal to the maximum distance between a flat reference surface and the lower surface of the sheet or plate, and L is equal to the minimum distance between points of contact of the sheet or plate with the flat reference surface.

If a general bow in the material can be eliminated by slight pressure without ends coiling or an "oil can" effect resulting, the material will be accepted.

6. OTHER REQUIREMENTS

When indicated on purchase orders, requirements not listed above or requirements more severe than those listed above which are referenced by a supplier's manufacturing specification will be adhered to.

7. TEST REPORTS

The manufacturer shall furnish five copies of a certified test report showing the results of the tests specified in Sections 3, 4, and 5 and bearing a statement as to the condition of the material as specified in Section 2.2. The report shall show the Purchase Order Number; P D Specification Number including dash number and sub letter; Per Cent of the Final Reduction; Temperatures of the Anneals Before and After the Final Reduction; Dimensions; Heat Number; and Name of Manufacturer.

8. PACKING AND MARKING

8.1 PACKING: The sheet or plate shall be packed in such a manner as to prevent injury during shipment.

8.2 MARKING: Each sheet or plate shall be marked showing the P D Specification and Dash Number; Heat Number; Manufacturer's Identification; Nominal Thickness in Inches. The marking shall be sufficiently stable to withstand ordinary handling.

TABLE I

CHEMICAL COMPOSITION

Element	Per Cent						
	Cb 1--1	Cb 1 -2	Cb 1 -3	Cb 1 -4	Cb 1 -5	Cb 1 -6	Cb 1 -7
Tantalum	----	----	26.0 - 29.0	----	9.0 - 11.0	----	----
Tungsten	----	9.0 - 11.0	10.0 - 12.0	9.0 - 11.0	9.0 - 11.0	9.0 - 11.0	4.5 - 5.5
Vanadium	4.5 - 5.5	----	----	----	----	----	----
Molybdenum	4.5 - 5.5	----	----	----	----	----	----
Hafnium	-----	----	----	----	----	9.0 - 11.0	----
Zirconium	0.75 - 1.3	0.75 - 1.25	0.6 - 1.1	2.0 - 3.0	----	----	0.70 - 1.20
Ytrium	----	----	----	----	----		0.30 - 0.70
Oxygen	0.030 max.	0.040 max.	0.030 max.	0.020 max.	0.010 max.	0.030 max.	0.04 max.
Nitrogen	0.020 max.	0.010 max.	0.020 max.	0.010 max.	0.0075 max.	0.015 max.	0.03 max.
Carbon	0.020 max.	0.08 - 0.12	0.020 max.	0.015 max.	0.005 max.	0.002 max.	0.04 - 0.08
Hydrogen	0.0020 max.	0.0020 max.	0.002 max.	0.001 max.	0.002 max.		0.002 max.
Columbium	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

VII. APPENDIX B

Materials Questionnaire and Cover Letter

TEXT OF QUESTIONNAIRE COVER LETTER

SUBJECT Westinghouse Purchase Order ________

The B-66 sheet, plate, and wire requisitioned on our purchase order will be used in fulfilling Westinghouse obligations to the Space Electric Power Office, Lewis Research Center, under Contract NAS 3-2540. In this program refractory metal alloys which have promising properties for applications in space power systems will be evaluated for weldability and long-time elevated temperature stability.

In conducting this evaluation, we feel it is in the best interest of all parties involved that suppliers of material are generally familiar with program objectives and requirements. This is important to us since we must rely on suppliers to provide a high quality representative product, and also technical information essential in our evaluation and interpretation of results. Likewise, we are sure that your interest in this program is in obtaining a fair evaluation of B-66.

The welding and thermal stability studies represent two phases of a rather extensive materials evaluation being sponsored by NASA. The ultimate objective is to identify the most promising alloys for various space power systems applications. Mechanical properties, weldability, corrosion resistance, and thermal stability studies are included in the overall program.

The validity of the technical evaluation of B-66 in our program is dependent on the quality of material supplied, and whether or not it is in fact representative of current manufacturing processes. Naturally, non-representative material would seriously compromise our effort. In this respect we must rely entirely on your organization since adequate technical data for preparation of tight specifications are not available. In addition, it is not our intention to be restrictive in any sense other than requiring good quality.

As you can well realize, our ability to make an adequate evaluation will depend, to varying degrees, on the availability of specific as well as general background information on the material you furnish. We have attached a short questionnaire covering several areas in which specific data on the material being furnished would be helpful. Would you kindly complete this questionnaire as soon as possible following shipment of our order. It is not our intention, nor do we wish to imply, that you should include proprietary information. However, any information which you feel free to provide would be appreciated.

Thank you for your attention in this matter. Please feel free to contact us should you have any questions.

WESTINGHOUSE ASTRONUCLEAR LABORATORY MATERIALS QUESTIONNAIRE

Please supply specific information on material furnished except where otherwise indicated.

Purchase Order No.____________________

Alloy____________________

Manufacturer____________________

	0.035" Sheet	0.375" Plate	0.082" Wire
1. Heat No.			
Ingot Size			
Melting Method (Arc, Double Arc, EB, etc.)			
2. Finished Condition (Stress Relieved, Recrystallized)			
Finish Anneal (Time, Temp., Atmosphere)			
Last Reduction (% Red. in area)			
Condition Before Final Red.			
Pre-Reduction Anneal			
3. Tensile Properties (List or Attach)			
Room Temp. 0.2%Y.S.			
Ult.			
%EL			

Elevated Temp.	0.2%Y.S.	________	________	________
________ °F	Ult.	________	________	________
	%El	________	________	________
________ °F	0.2%Y.S.	________	________	________
	Ult.	________	________	________
	%El	________	________	________
________ °F	0.2%Y.S.	________	________	________
	Ult.	________	________	________
	%El	________	________	________

Also indicate: Strain Rate, Specimen Size, Atmosphere, Gage Length, or Reference Test Procedure

Other Mechanical Property Tests, List:

4. Chemistry (Finished Product)

________	________	________
________	________	________
________	________	________
________	________	________
________	________	________
________	________	________

What sampling technique was used?

5. Typical Welding Parameters (Straight Polarity TIG and EB)

Sheet Tk.	Current (Amperes)	Volts	Speed	Arc Gap	Shielding Gas(?) or Vacuum

6. Are there any unrealistic or compromising requirements in our Tentative Specification WANL________________which you feel will either prejudice our results in evaluating____________or are inconsistent with your anticipated applications for this alloy? Please explain.

7. Have you tailored your processing of this material for our program, i.e., for improved weldability, thermal stability or ductility, at the expense of other properties such as tensile or creep strength? Please explain.

8. Would you please attach technical data or list references describing the effects on properties of interstitial level variations in________________.

9. Would you please attach any recommended metallographic procedures for __________________which you have available.

10. Are there any special cleaning and pickling procedures which you would recommend?

11. If there is any other information you feel we should have for our evaluation, please include it.

VII. APPENDIX C

Bend Ductility Data Sheets

ALLOY Ta-10W

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base (2)			Re-XL Base (3)			Weld Metal			
						Min Rad. (1)	°F Temp.	(4) R.	Min Rad. (1)	°F Temp.	(4) R.	Treat-ment	Min Rad. (1)	°F Temp.	(4) R.
23	Base History Unknown	.040"				< 1T							1T (5)		

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius
(5) Electron Beam Welding

ALLOY T-111

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base (2)			Re-XL Base (3)			Weld Metal			
						Min Rad. (1)	°F Temp.	(4) R.	Min Rad. (1)	°F Temp.	(4) R.	Treat-ment	Min Rad. (1)	°F Temp.	(4) R.
2			T	Face	1		-320	2T		-320	2T	S. R.		-320	2T
			T	Face	1							Re-XL		-320	2T
22					1	<1T						As Welded	1.3T	-200	2T
23	>1T Base Condi-tion Unknown	.040"											1T		

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

ALLOY T-222

Data Source Ref.	Comments	Thickness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base (2)			Re-XL Base (3)			Weld Metal			
						Min. Rad. (1)	°F Temp.	R. (4)	Min. Rad. (1)	°F Temp.	R. (4)	Treatment	Min. Rad. (1)	°F Temp.	R. (4)
3		.060"	L	Face	1							S.R. Re-XL		-250 -250	2.5T 2.5T

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

ALLOY AS-55

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base(2) Min. Rad.(1)	S.R. Base(2) °F Temp.	S.R. Base(2) (4) R.	Re-XL Base(3) Min. Rad.(1)	Re-XL Base(3) °F Temp.	Re-XL Base(3) (4) R.	Weld Metal Treat-ment	Weld Metal Min. Rad.(1)	Weld Metal °F Temp.	Weld Metal (4) R.
15							-100	.37T							
												Base S.R.		-100 -100	4T 4T
9		.060"	L	Face	2	.37T	-100	.37T				Re-XL	.74T	-100	4.4T
	1 hr. 2600°F pre-treat & 1 hr. 2400°F post													-100	.26T
	1 hr. 2800° } 1 hr. 2400° } pre-treat & 100 hrs. 1800°F post													-100	2.1T

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

ALLOY B-66

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base (2) Min. Rad. (1)	S.R. Base (2) °F Temp.	S.R. Base (2) (4) R.	Re-XL Base (3) Min. Rad. (1)	Re-XL Base (3) °F Temp.	Re-XL Base (3) (4) R.	Weld Metal Treat ment	Weld Metal Min. Rad. (1)	Weld Metal °F Temp.	Weld Metal (4) R.
21		.040"							< 1T				5T		
13		.042"	L	Face	10	1T	-320	1T		-50	4T		2.5T	0	3T
15							-300			-300					
													2.5T	78	2.5T
														-20	4T
							-320	1T		-320			2.5T	78	2.5T
7			L	Face	10	1T	-320	1T							
14	Electron Beam Welding	.020"	L	Face	.2					-320	1T			78	1T
17		.020"	L	Face	.2							As Welded		-50	1T

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

ALLOY C-129Y

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base (2)			Re-XL Base (3)			Weld Metal			
						Min. Rad. (1)	°F Temp.	(4) R.	Min. Rad. (1)	°F Temp.	(4) R.	Treat-ment	Min. Rad. (1)	°F Temp.	(4) R.
6												Re-XL	$\frac{1}{2}$T	-150	4T

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

ALLOY Cb-752

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base (2) Min. Rad. (1)	S.R. Base (2) °F Temp.	S.R. Base (2) (4) R.	Re-XL Base (3) Min. Rad. (1)	Re-XL Base (3) °F Temp.	Re-XL Base (3) (4) R.	Weld Metal Treat-ment	Weld Metal Min. Rad. (1)	Weld Metal °F Temp.	Weld Metal (4) R.
18		.030"	L	Root	.2		-320	1T		-320	1T	Re-XL		-230	1T
15							-320	1T		-320	3T				
							-320	4T		-320	3T			78	3T
														78	2T
														32/-40	4T
19	2400° S.R.	.030"				1T							2T		
5						1T			1T				2T		
20			T		10	1T	-200	3T	1T	-320	3T				
			T		10							Base Re-XL	10T		
	4 hrs. 1850°F		T		10								3T		
	1 hr. 2200°F		T		10								1T		
14	30"/min welding speed		L	Face	.2							Re-XL		78	1T
	7.5-15"/min welding speed													78	1T

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

ALLOY D-43*

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base(2) Min. Rad.(1)	S.R. Base(2) °F Temp.	S.R. Base(2) (4) R.	Re-XL Base(3) Min. Rad.(1)	Re-XL Base(3) °F Temp.	Re-XL Base(3) (4) R.	Weld Metal Treat-ment	Weld Metal Min. Rad.(1)	Weld Metal °F Temp.	Weld Metal (4) R.
18		.040"			.2									-150	1½T
15							-100	2T						-150	
														78	2T
							-100	2T						78	
14	As Welded													-100	1T
	Aged 1800°F 4-24 hrs., 2000°F 2 hrs.		L	Face	.2									100	1T
	2000°F 8 hrs.													-180	1T

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

* Originally designated X110

ALLOY FS-85

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base (2)			Re-XL Base (3)			Weld Metal			
						Min. Rad. (1)	°F Temp.	(4) R.	Min. Rad. (1)	°F Temp.	(4) R.	Treat-ment	Min. Rad. (1)	°F Temp.	(4) R.
21		0.40"				< 1T							< 1T		
15							-320			-320					
														75	4T
							-320			-320				75	4T
10		.060" / .187			10	$\frac{1}{4}$T									
14	Electron Beam Welded						-320	1T						-100	1T
17		.020"	L	Face	.2									-250	1T

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

ALLOY SCb-291

Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base(2)			Re-XL Base(3)			Weld Metal			
						Min. Rad.(1)	°F Temp.	(4) R.	Min. Rad.(1)	°F Temp.	(4) R.	Treat-ment	Min. Rad.(1)	°F Temp.	(4) R.
15							-320	1T		-320				-275 -275	2T

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

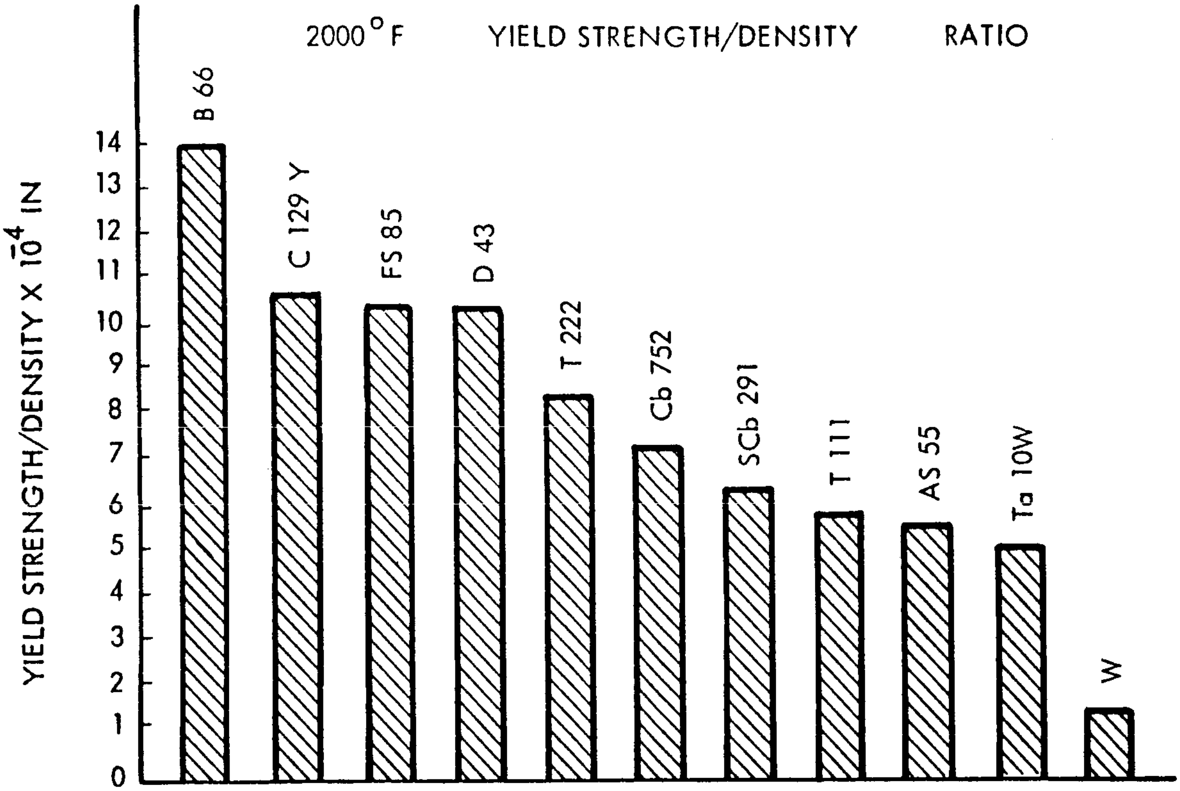
ALLOY W-26 Re

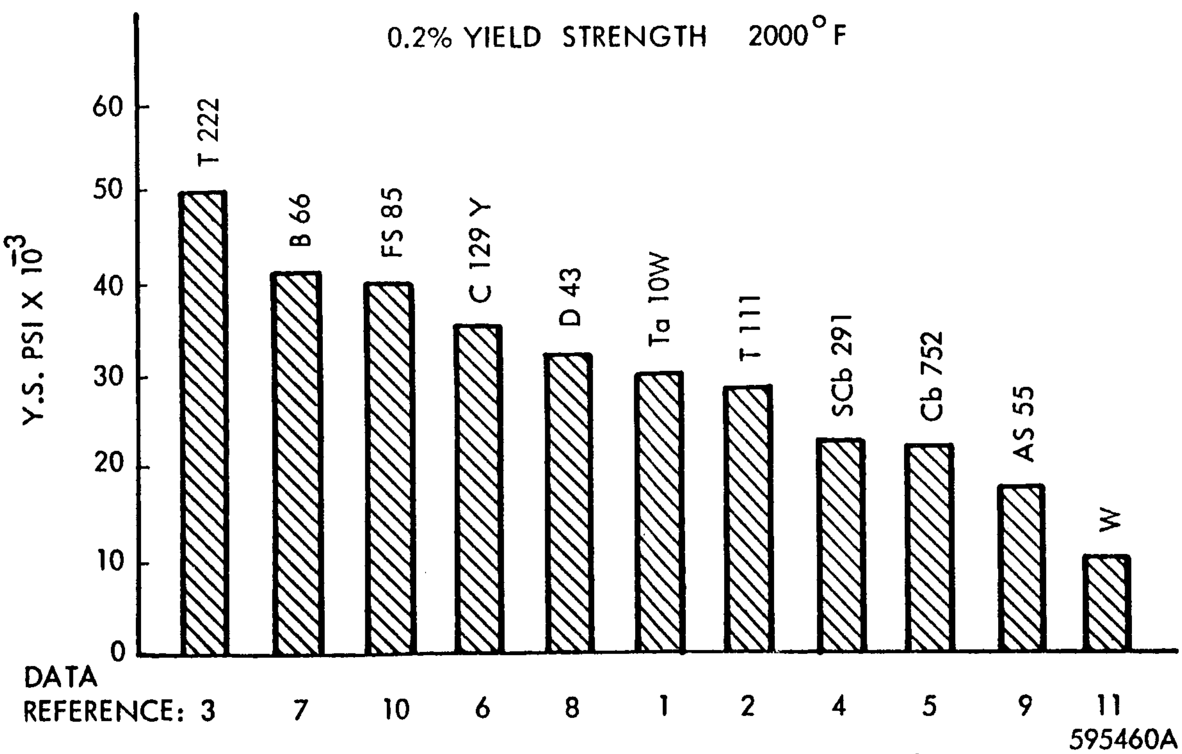
Data Source Ref.	Comments	Thick-ness	Long. or Trans	Tension Side	ipm Ram Speed	S.R. Base (2)			Re-XL Base (3)			Weld Metal			
						Min. Rad. (1)	°F Temp.	(4) R.	Min. Rad. (1)	°F Temp.	(4) R.	Treat-ment	Min. Rad. (1)	°F Temp.	(4) R.
25		.020"				1T			1T	-100	4T				
26							-200			-100					

(1) At Room Temperature
(2) Stress Relieved
(3) Recrystallized
(4) Radius

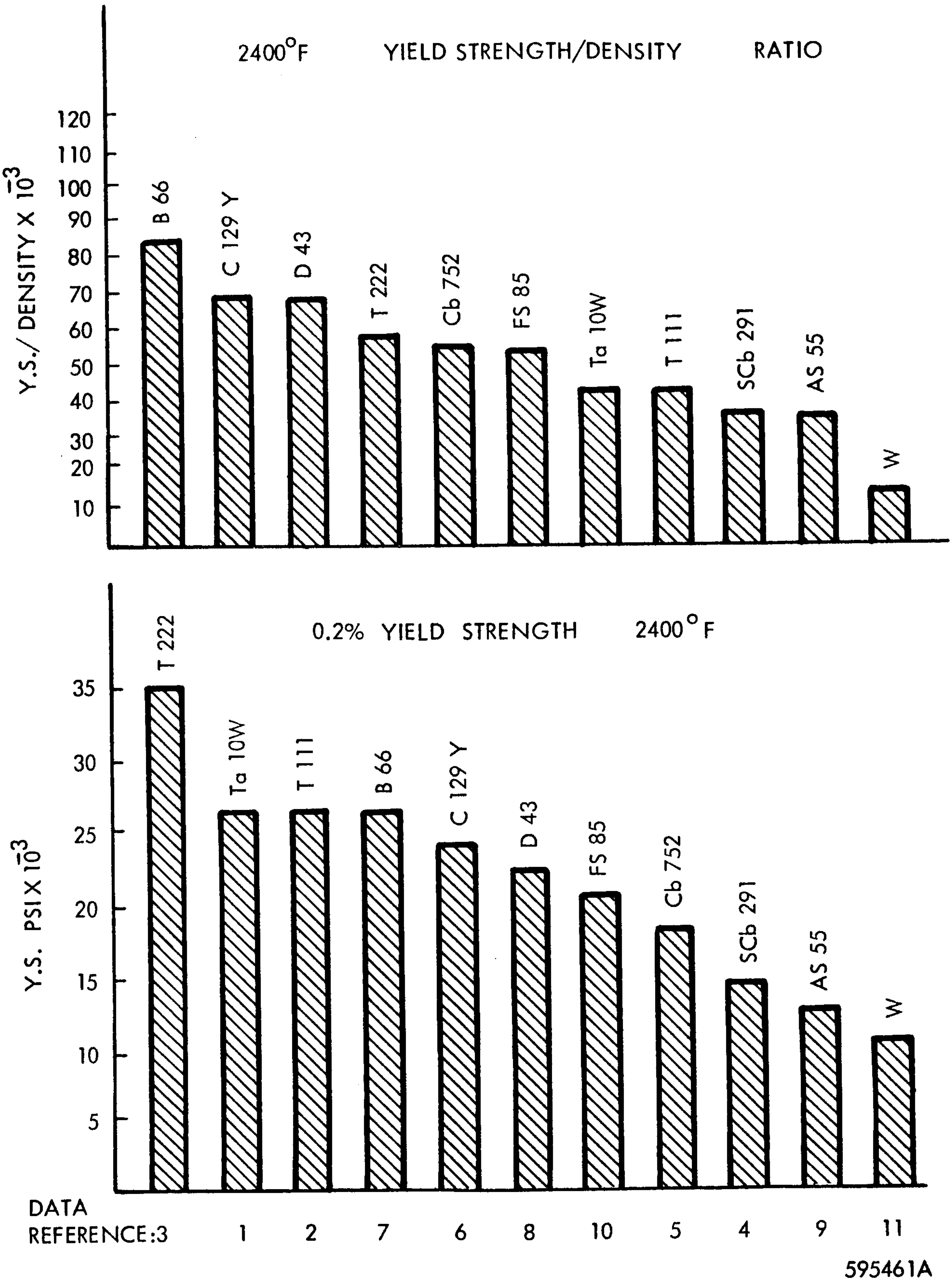
VII. APPENDIX D

Reported Tensile Properties For Alloys Being Evaluated





Short Time Tensile Properties at 2000°F



Short Time Tensile Properties at 2400°F

TENSILE TEST CONDITIONS AND MATERIAL HISTORY FOR
TENSILE DATA SUMMARIES

Alloy	Material Size	Material History	Test Atm.	Strain Rate in/in/min	Comments	Source
Ta-10W	.060"	Recrystallized	---	------		1
T-111	.050"	Recrystallized 1 hr.-3000°F	Vac.	.05		2
T-222	.060"	Recrystallized 1 hr. 3000°F	Vac.	..05		3
SCb-291	----	Annealed	Inert	.05		4
Cb-752	.030"	-------	Vac.	.005		5
C-129Y	.040"	Recrystallized 1 hr.-2400°F	---	.005		6
B-66	----	Recrystallized 2500-2700°F	Vac.	.05		7
D-43	.040"	Stress-relief 1 hr.-2200°F	---	------		8
AS-55	.060"	1 hr.-2800°F + 1 hr.-2400°F	---	.01		9
FS-85	-----	Cold rolled sheet	---	------		15
W Arc Cast		Recrystallized	---	------		11